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The Case for Asymmetric Dust Around a C-Rich AGB Star

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ABSTRACT
$JHKL$ observations of the mass-losing carbon Mira variable IRAS 15194–5115 (II Lup) extending over about 18 years are presented and discussed. The pulsation period is 575 days and has remained essentially constant over this time span. The star has undergone an extensive obscuration minimum during this time. This is complex and, like such minima in similar objects, e.g. R For, does not fit the model predictions of a simple long term periodicity. Together with the high resolution observations of Lopez et al. the results suggest that the obscuration changes are due to the formation of dust clouds of limited extent in the line-of-sight. This is an RCB-type model. The effective reddening law at J and H is similar to that found for R For.

Key words: stars: AGB and post-AGB - stars: carbon - circumstellar matter - stars: mass loss - variables:other -infrared:stars

1 INTRODUCTION

IRAS 15194–5115 (II Lup) was classified as a carbon star by Epchtein et al. (1987) and Meadows et al. (1987). At 12μm it is the third brightest carbon star in the sky. It is a Mira variable for which Le Bertre (1992) gave an approximate period of 580 days. The circumstellar environment of the star has been studied by a number of workers. For instance Ryde et al. (1999) modelled the radio and far infrared rotational lines of CO, whilst Groenewegen et al. (1998) modelled the infrared spectral energy distribution. The star has similarities to the proto-type mass-losing carbon Mira IRC+10 216 (CW Leo) which has a pulsation period of 630 days. Ryde et al. derive a mass-loss rate of $1 \times 10^{-5} M_{\odot} yr^{-1}$ for II Lup and suggest that the wind characteristics of the object have not changed over the past few thousand years. However, they note that their data do not preclude variations in the mass-loss rate in the inner parts of the circumstellar material by a factor of three. Both Ryde et al. and Groenewegen et al. find that the dust-to-gas ratio in II Lup is about twice that in the envelope of CW Leo. However, the main difference between II Lup and CW Leo is in the $^{12}C/^{13}C$ ratio. Ryde et al. estimate this as 5.5 for II Lup. Whereas Kahane et al. (1992) found 44 ± 3 for CW Leo. One possibility, suggested by Ryde et al. for the relatively low ratio in II Lup, is that the star has recently gone through a period of hot-bottom burning.

Drops in the near infrared brightness of a carbon Mira on a time-scale long compared with the pulsation period, were first seen in the Galactic Mira R For (Feast et al. 1984). In that case a decline at visual wavelengths was also reported. These events were attributed to increased absorption in the line-of-sight. Further observations of R For were published by Le Bertre (1992). The most extensive investigation of this phenomenon is that of Whitelock et al. (1997) who discuss the near-infrared light curves of 11 large amplitude carbon variables from data covering time periods of from 9 to 22 years together with visual observations for some of them.

Here we present and discuss $JHKL$ (1.2, 1.6, 2.2 and 3.5 μm) observations of II Lup over a time period of about 18 years. The results are of particular interest for at least three reasons. (1) During this time period the object underwent an extended obscuration phase. (2) The pulsation variations are well covered, early and late in the time period involved. (3) At one point during the obscuration phase, infrared speckle observations (Lopez et al. 1993) provide estimates of the relative contributions of the starlight and the dust-shell emission in the infrared. These estimates are helpful in interpreting the data presented here.

2 OBSERVATIONS

The SAAO near infrared photometry of II Lup is listed in Table 1. The times of the observations are given as Julian Date (JD) from which 2440000 has been subtracted. The $JHKL$ measurements were all made with the MKII pho-

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tometer on the 0.75m telescope at SAAO, Sutherland. They are on the current SAAO system as defined by the standards of Carter (1990). The photometry is accurate to better than $\pm$0.03mag at JHK and to better than $\pm$0.05mag at L. Three of the early measurements were published by Lloyd Evans & Catchpole (1989). This is the star called WO48 in that paper, but note that two of the JDs were inadvertently transposed there.

3 DISCUSSION

3.1 The Light Curves

Figure 1 shows the $JHKL$ light curves The figure also includes as crosses the measurements from Le Bertre (1992) as well as the observations from Epchtein et al. (1987), Meadows et al. (1987) and Groenewegen et al. (1993). There are likely to be differences between the various photometric systems. This is clearly seen at L where an L' filter was used by the ESO observers. There is no clear evidence of a significant difference between the SAAO J data and that of the other observers. In any case the non-SAAO data are not used except to define the general shape of the light variations. The very bright L' magnitude at JD 2448314 is from Groenewegen et al. (1993). Their JHK measures do not appear unusual. They only report this single observation and we have not considered their L' measurement in the later discussion.

In the following we concentrate on discussing the J and L light curves. Those at H and K are intermediate between these. Fig. 2 shows the fit to the J data of a sinusoid with $P_0 = 575$ days and a long-term trend, modelled as sinusoid with $P_1 = 12 \times P_0$; a small contribution is also made by the first harmonics of the two periods, $P_0/2, P_1/2$. The data stream is not long enough to determine the nature of the long-term trend and the fact that it can be represented in this way is probably fortuitous.

The 575 day period, which we take as the pulsation period, is well defined. This is only a slight revision of the period of 580 days given by Le Bertre (1992). Evidently this revised period satisfies the early observations (i.e. JD 2447000-2448000) when the object was faint at J and also the later ones (JD 2451600-2452600) when it was bright at J. This apparent constancy of the period suggests that there has been no significant changes in the properties of the underlying star during the period of observation. The amplitudes of the pulsation are slightly smaller at the brighter epoch (by $\sim$ 0.2 mag at J, $\sim$ 0.4 mag at H, $\sim$ 0.2 mag at K and $\lesssim$ 0.1mag at L). In view of the known irregularities of Mira light curves it is not clear whether these small changes have any important significance. However, they may be due to changes in the relative contributions of the starlight and the dust emission to the total flux at the early and late epochs (see below).

The near constancy of the mean L brightness is striking compared with the large changes at J (a range of more than two magnitudes). There is, however, a small increase in the brightness at L (of about 0.1mag) between the early (faint) and later (bright) epochs.

It is evident from Fig. 1 that the mean brightness of II Lup at J underwent an extended minimum lasting from at

Table 1. SAAO Near-infrared photometry for II Lup

(JD) −2440000	J	H (mag)	K	L
5938.26	5.95	3.40	1.46	–0.80
6309.28	7.90	4.97	2.66	0.04
7214.61	7.32	4.34	2.01	–0.69
7240.54	7.43	4.42	2.09	–0.60
7263.51	7.58	4.56	2.21	–0.52
7280.46	7.72	4.70	2.31	–0.38
7329.37	8.16	5.11	2.65	–0.10
7356.32	8.43	5.34	2.87	0.05
7392.25	8.60	5.56	3.07	0.18
7608.43	8.22	5.24	2.74	–0.15
7686.40	7.76	4.79	2.34	–0.44
7720.27	7.66	4.67	2.24	–0.54
7743.25	7.60	4.64	2.24	–0.52
7989.57	8.72	5.78	3.27	0.28
8093.28	8.64	5.76	3.28	0.38
8380.50	7.47	4.60	2.21	–0.53
8434.33	7.72	4.84	2.44	–0.39
8458.29	7.85	4.99	2.59	–0.27
8706.54	8.08	5.42	3.07	0.18
8748.53	7.71	5.02	2.69	–0.08
8793.32	7.27	4.58	2.30	–0.44
9003.55	7.24	4.48	2.22	–0.48
9168.32	8.23	5.41	3.11	0.32
9236.26	8.26	5.40	3.07	0.28
9502.44	7.51	4.52	2.16	–0.61
9589.25	8.26	5.15	2.67	–0.24
9831.59	9.21	6.09	3.46	0.39
10234.38	8.97	5.71	3.12	0.12
10256.37	9.09	5.82	3.22	0.27
10478.60	8.35	5.17	2.63	–0.23
10503.58	8.18	5.01	2.49	–0.37
10589.48	7.78	4.61	2.14	–0.60
10618.35	7.75	4.58	2.11	–0.62
10802.59	8.24	5.21	2.72	–0.05
10995.51	7.92	5.07	2.71	0.07
11053.51	7.43	4.67	2.38	–0.25
11235.48	6.71	4.04	1.84	–0.71
11300.46	6.71	4.11	1.98	–0.53
11352.43	6.85	4.26	2.17	–0.23
11417.23	6.95	4.39	2.35	0.03
11613.54	6.39	4.00	2.04	–0.22
11678.41	5.88	3.56	1.68	–0.59
11712.35	5.56	3.28	1.49	–0.71
11747.26	5.42	3.13	1.39	–0.79
11782.26	5.48	3.17	1.41	–0.75
11963.57	6.18	3.81	1.97	–0.15
11979.57	6.22	3.85	2.02	–0.10
12033.47	6.32	3.95	2.13	0.01
12068.40	6.35	4.00	2.18	0.12
12116.33	6.34	3.98	2.18	0.09
12128.29	6.32	3.97	2.14	0.07
12159.24	6.09	3.79	1.99	–0.06
12178.22	5.80	3.54	1.78	–0.26
12322.59	5.29	3.04	1.35	–0.76
12324.62	5.30	3.05	1.34	–0.79
12347.60	5.38	3.15	1.46	–0.74
12382.50	5.40	3.11	1.39	–0.69
12426.33	5.56	3.24	1.48	–0.61
12457.31	5.69	3.34	1.59	–0.49
12524.23	6.24	3.79	1.94	–0.14
12690.64	6.52	4.00	2.14	0.04

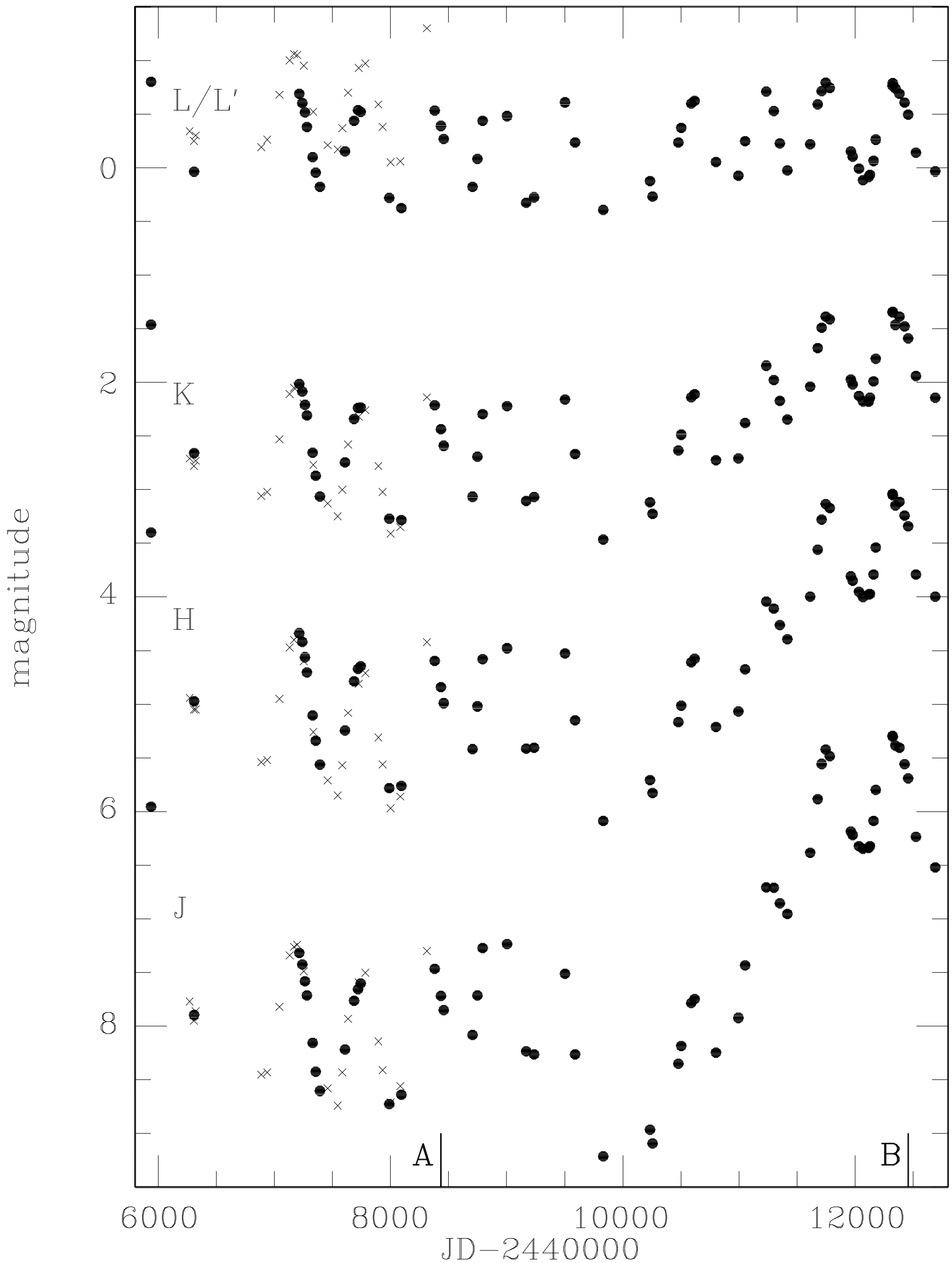

Figure 1. A plot of the $JHKL$ magnitudes of II Lup against JD. Non-SAAO observations are shown as crosses; see text for details

least JD ∼ 2445800 to JD ∼ 2451800. Despite the sparseness of the data at some epochs it is clear that the J variations during this period were complex and that the curves shown in Fig. 2 provide only an approximate fit to the long term variations. There was evidently a steep decline in mean J brightness near JD 2446000. Between JD ∼ 2447000 and JD ∼ 2449200 there appears to have been a further, slower, decline followed by a rise in brightness. A relatively steep decline followed at JD ∼ 2449600. From JD ∼ 2450500 to the end of the time period under discussion (JD 2452500), the object has been brightening at J.

It is of interest to compare the brightness variations

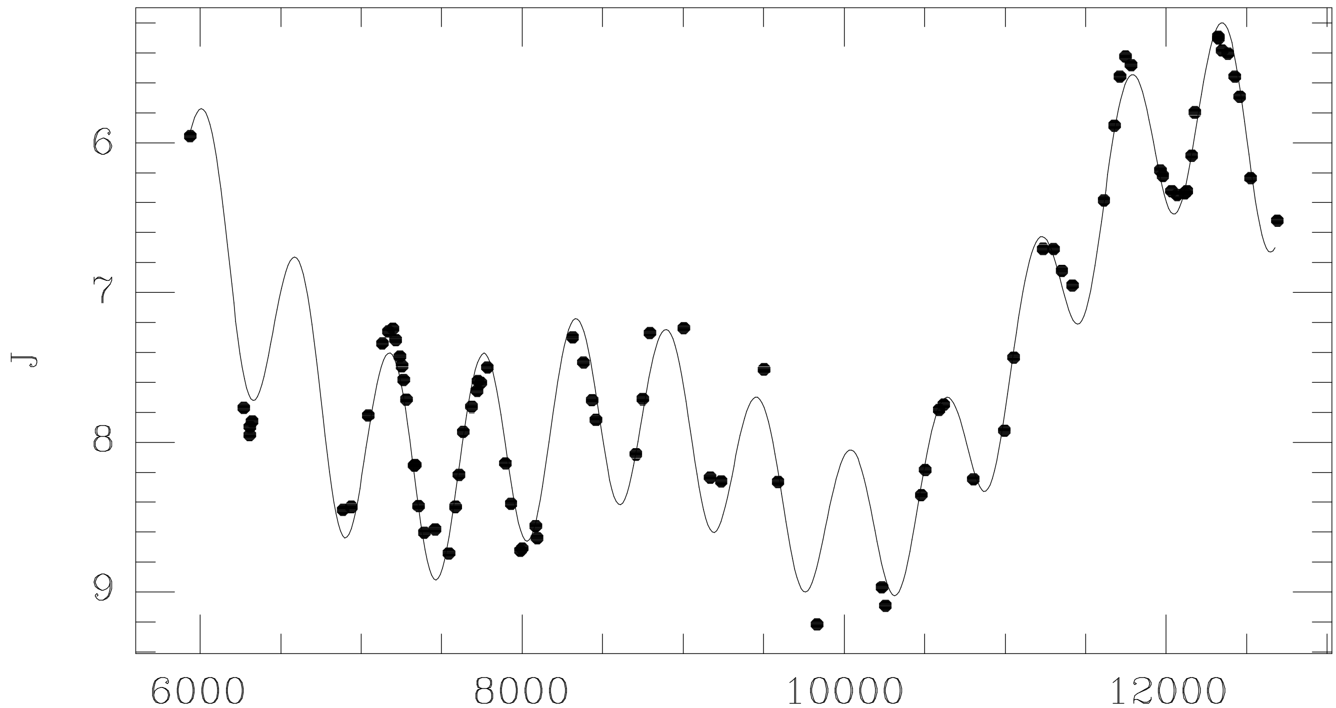

Figure 2. The J magnitudes of II Lup plotted against JD–2440000 with a curve showing the combination of periods of 575 and 6900 days and their first harmonics.

of II Lup at J with some theoretical models. There has been extensive work over a number of years on the connection between pulsation, mass-loss and dust formation. See, for instance, the summaries and references to earlier work by two particularly active groups in Sedlmayr & Winters (2000), Fleischer et al. (2000), Winters (2003), Höfner & Dorfi (1997), Sandin & Höfner (2003), and Andersen et al. (2003). This work has centred on the formation of shock waves and dust in the circumstellar environment. A paper by Winters et al. (1994) makes predictions about the long term light curves expected from models of this type. These predictions are sensitive to the C/O element abundance ratio adopted in the models, as was particularly emphasized by Fleischer et al. (2000). For relatively high values of the ratio (~ 1.8) no long term modulation of the light curve is predicted. However, for lower values (e.g. ~ 1.3) a long term periodicity is predicted, new dust being formed not every pulsation cycle but on a longer, periodic, time scale. Such a simple periodicity is not apparent in the behaviour of the J brightness of II Lup just described. This result is similar to that obtained by Whitelock et al. (1997) for a number of other carbon Miras. These authors pointed out that the infrared light curves of R For were complex and did not conform to the model predictions. R Vol and R Lep were similar to R For.

There are some carbon variables, e.g. R Scl (Whitelock et al. 1997), which may show long-term periodic modulation in their infrared light curves, though this needs confirmation. Note that the carbon variable V Hya with a secondary (optical) period of ~ 6160 days (Mayall 1965, Knapp et al. 1999, Olivier et al. 2001) is thought to be in a binary orbit of this period. However, it would appear that in general carbon Miras do not show the long term periodic modulation predicted by some models. The long term variations of these stars are much less regular. It may be noted that the model of Winters et al. (1994) has been criticized by Groenewegen (1997) in its application to CW Leo because it requires a different distance for the object to fit the 11 μm visibility curve from that needed to fit the spectral energy distribution. We may conclude that whilst such theoretical models may well form the basis for further advances, they do not fit all the observations. The current models are based on spherically symmetrical systems. In the next section we give reasons for supposing that there were significant departures from spherical symmetry in the case of the II Lup during the time period under discussion.

3.2 Evidence for a Dust Cloud Model

In view of the apparent constancy of the pulsation period through the time period of the observations discussed above, we assume in the following that there has been no overall change in the underlying star. The tentative suggestion (Whitelock et al. 1997) that in the case of R For an apparent change in pulsation period might be associated with a change in mass-loss rate, needs further investigation.

Infrared speckle observations of II Lup were obtained by Lopez et al. (1993) on JD 2448434 when the object was in the obscuration minimum (see Fig. 1 or 2). These workers used their observations together with a spherically symmetrical model to estimate the relative contributions of the dust emission and starlight to the total flux at various wavelengths. In view of the departure from spherical symmetry which we are suggesting in the present paper, the numerical results derived by Lopez et al. have to be treated with caution. Nevertheless it seems safe to assume from their work

that at this time almost all of the flux at L came from the dust shell whilst almost all of the flux at J was starlight. The near constancy of the mean L flux throughout the period of our observations then suggests a constant dust shell. On the other hand the variations at J suggest changes in the shell opacity in the line-of-sight. This evidently requires an asymmetric model.

To roughly quantify these results we adopt the proportions of flux from the star and the shell at different wavelengths as given by Lopez et al. Table 1 shows that (by chance) we have a $JHKL$ observation on the same day as their observation. The object was then around phase 0.16 in the pulsation cycle. Lopez et al. (see their fig. 6) interpret their results to show that at that time there was a negligible contribution of heated dust in the shell to the flux at J. Most of the J flux was direct starlight though about 10 percent of the flux was scattered starlight. In contrast, at L 80 percent of the flux was dust emission and only 20 percent starlight.

Towards the end of the time period under discussion, when the object was bright at J, it was observed at almost exactly the same pulsation phase as that of the speckle work (JD 2452457 see Table 1). Call this epoch B and the epoch of the speckle work A (these epochs are marked in Fig. 1). Suppose the variation in J between A and B is due to a change in dust absorption. The speckle work indicates that at epoch A 15 percent of the flux at H was from heated dust. Adopting this value and assuming that the flux from heated dust remained constant, it follows from the photometry at A and B that the effective absorption law of the dust is $\Delta J_*/\Delta H_* = 1.24$, where the asterisk indicates the stellar component of the flux[1]. This is similar to the effective reddening law found for the carbon Mira R For (Feast et al. 1984) which gives 1.33 for this ratio. The uncertainty of this quantity is difficult to estimate, but may be about 0.1 in the case of both variables. This agreement with R For, which has much bluer $J-L$ colours (see below), suggests that the conclusions of Lopez et al. (1993), assigning the bulk of the J flux to the stellar contribution, are broadly correct. In connection with their discussion of circumstellar dust formation round carbon variables, Andersen et al. (2003) consider three types of carbon-rich particles using data taken from Rouleau & Martin (1991) and Jäger et al. (1998). The predicted values for the above ratio range from 1.36 to 1.85 for the three types of particle. The rough agreement with the values actually observed is probably as good as can be expected in view of both observational and theoretical uncertainties. The fact that the speckle work indicates that dust emission contributes a large fraction (50 percent) of the flux at K at epoch A, makes it impractical to extend this type of calculation to wavelengths longer than H.

If 80 percent of the flux at L is from dust emission at epoch A then $L_{sh} = -0.15$, where the subscript "sh" denotes shell, and $L_* = +1.36$. The work on R For (Feast et al. 1984) gave $\Delta J/\Delta L \sim 4.0$ as the effective reddening ratio of the circumstellar shell. This value is uncertain as it might be affected by (an unknown) shell-emission component at L. But note that the range covered by the infrared colours of R For used to determine the reddening law are bluer than those of II Lup (e.g. a range in $(J-L)_0$ of 4.5 to 5.4 for R For compared with values for II Lup at epochs A and B of 8.0 and 6.0). Thus the contribution of dust emission to the L flux is likely to be lower for R For than for II Lup. The three dust models considered by Andersen et al. (2003) predict the ratio $\Delta J/\Delta L$ to be in the range from 3.2 to 5.8. If the shell flux at L has remained constant between epochs A and B we can use an adopted ratio $\Delta J_*/\Delta L_*$ to predict the brightening of the stellar component of L, and hence the expected total brightness at L. For adopted values of $\Delta J_*/\Delta L_*$ of 3, 4, 5 and 6 one then predicts the L magnitudes at epoch B to be $-0.55, -0.51, -0.49$ and -0.47. The observed value is -0.49. Considering the various uncertainties there is no disagreement with this range of models. We may conclude that the observations are consistent with the hypothesis of constant emission from the shell and a varying stellar component between epoch A and B due to variable dust absorption.

It may be noted that if we ascribed the increase in brightness at J between epochs A and B to an increase in the emission flux from the dust, then the dust flux at J would need to increase by about 6 magnitudes. A similar increase at longer wavelengths is then anticipated unless the temperature structure of the shell changed markedly. Any such change would have to take into account that the pulsation amplitudes are little affected by the rise in brightness. Although the J flux at B would then be essentially all from the dust flux whilst at A it is essentially all starlight. In addition the total L flux has to be kept nearly constant. We therefore discard this possibility.

We might anticipate that if the increase in brightness at J between A and B were due to the dispersal of a spherical shell of dust, then the circumstellar dust emission would be reduced at the same time. An estimate of this reduction could be made if we knew the intrinsic colours of the underlying star. These are not known. However, the carbon Miras in the LMC discussed by Feast et al. (1989) are all relatively bright optically and $J-H$ is likely to be only slightly affected by circumstellar reddening. These twenty Miras have $\overline{J-H} = 1.23$ with a range of individual values from 0.70 to 1.67. The five carbon Miras with periods greater than 350 days have $\overline{J-H} = 1.39$ and a range 1.21 to 1.67. The longest period Mira in this group has a period of 418 days and $J-H = 1.30$. The above values need to be corrected for the interstellar reddening of the LMC stars. This is expected to be small ($E_{(J-H)} \sim 0.03$ from Feast et al. 1989). The optically bright (unobscured) carbon Miras in our Galaxy cover a similar range in $(J-H)_0$ colours (Feast et al. 1982). One might expect the intrinsic colours of carbon Miras to increase with period. This is certainly the case for oxygen Miras. For the purposes of illustration we consider the consequences of adopting intrinsic colours $(J-H)_0$ of 1.0 or 1.5 for II Lup. We also adopt an interstellar absorption of $A_V = 0.8$ mag from Groenewegen et al. (1998). It is then straightforward to show that with 80 percent of the flux at L from the shell at epoch A, there would be a decrease in the total flux at L between A and B of 0.12 or 0.23 mag, assuming that the temperature of the dust emission remained constant. These figures account for both the expected decrease in the shell emission and the increase in starlight at L. In fact the decrease in obscuration at J between A and B is presumably due to to the dust concerned

[1] Without allowing for the dust component at H this ratio is 1.35

moving away from the star. Thus the temperature of this dust will decrease between A and B and the actual decrease in brightness at L will be greater than the figures just given. However, we in fact see a small increase (~ 0.1 mag) in the total flux at L between A and B which (as discussed above) can plausibly be attributed to the increase in direct starlight at the later epoch. These considerations suggest that we are not dealing with the dispersal of a complete dust shell. But with the clearing (due to expansion from the star) of a dust cloud of limited extent and in the line-of-sight. Note that for simplicity we refer to a dust cloud. However, in view of the relative complexity of the J light curve, ejection in the line-of-sight was presumably taking place over a considerable length of time and at a variable rate.

3.3 General Discussion

The conclusion reached above, that the long-term modulation of the light curves of II Lup is due to the ejection of a dust cloud (or clouds) of limited extent in the line-of-sight, leaving the circumstellar dust emission virtually unchanged, is consistent with other data on carbon Miras. In the case of R For, it was argued by Whitelock et al. (1997) that an obscuration phase was due to a dust cloud which could not be a complete spherical shell. These authors also point out that the bolometric absolute magnitude of R Lep calculated from observations from the near- to the mid-infrared and using the Hipparcos parallax of the object, is fainter than anticipated theoretically. This conclusion is not changed if one adopts the revised parallax of R Lep recently published by Knapp et al. (2003). Whitelock et al. (1997) note that this problem can be overcome if the circumstellar emission from R Lep is from a non-uniform shell with higher than average absorption in the line-of-sight.

One, extreme, model for a non-spherical dust shell would be a circumstellar disc viewed edge-on. Disc models have been suggested to explain polarization observations of the carbon variable RW LMi (GL1403) (Cohen & Schmidt 1982) which has some similarities to R For (see Whitelock et al. 1997). Theoretical disc models have also been proposed (Dorfi & Höfner 1996). Such a model might be appropriate for the unusual object V Hya (e.g. Dorfi & Höfner 2000) which is probably a binary (see above). However, it is not certain that it is applicable to carbon Miras in general. For instance if the disc is optically thick to starlight we would expect significant changes in apparent bolometric luminosity between pole-on and edge-on views. For a disc with total opening angle (measured at the centre of the star) of 20 degrees this would amount to about two magnitudes. The scatter of long period carbon Miras with dust shells in the LMC about a bolometric period-luminosity relation is less than one magnitude (Whitelock et al. 2003) and much of this is likely to be due to the very poor temporal coverage of the stars at mid-infrared wavelengths.

In the sample of LMC carbon Miras studied by Whitelock et al. (2003) there are four which show evidence of obscuration phases. These, together with their $K-[12]$ colours (outside major obscuration) are; IRAS 05300–6651, 7.29; TRM 72, 5.93; IRAS 05009–6616, 6.28; TRM 88, 4.44. The colours order the objects according to the relative contributions of the near- and mid-infrared to their bolometric fluxes. For the last three objects the near-infrared data are sufficient to allow a comparison between the bolometric magnitudes obtained using $JHKL$ values at the bright and faint phases of the obscurations. For these three stars (in the order given above) the differences between these values are only 0.1, 0.1 and 0.4 mag. The $K-[12]$ colours of the last of these, TRM 88, are amongst the smallest of the long period sample of carbon Miras used by Whitelock et al. to define a period-luminosity relation and the object has a large obscuration range ($\Delta K \sim 1$ mag). Thus the conclusion drawn above regarding the relative narrowness of the period-luminosity relation is not affected by the way the bolometric magnitudes were calculated by Whitelock et al.

The optically bright and relatively short period ($P <$ 420 days) carbon Miras in the LMC discussed by Feast et al. (1989) fit tight period-luminosity relations at K and M_{bol}. Such stars thus appear to have thin shells and their K and M_{bol} magnitudes are not seriously affected by circumstellar reddening. However, the Galactic carbon Mira, R Lep, mentioned above is an interesting intermediate case. With $K-[12]=2.41$ its near infrared flux will contribute more to a derived M_{bol} than in the case of the obscured LMC Miras mentioned above. Thus higher than average shell absorption in the line-of-sight could well lead to a considerable underestimate of the bolometric luminosity as suggested by Whitelock et al. (1997). II Lup, itself, with $K-[12]=3.39$ may also be in this category.

Further work on the obscured LMC stars might allow one to discriminate decisively between a model with a disc of large vertical extent and a quasi-spherical model. At present the latter seems the more promising for most of the stars. Both models require small scale variations due to dust clouds in order to explain object like II Lup unless one invokes a precessing disc model. Even then some non-uniform structure in the disc would be necessary to take into account the complexity of the variations at J.

There are a number of other observations which point towards non-uniform shell models. High resolution observations show that the inner region of the circumstellar material around CW Leo is highly structured and variable (e.g. Tuthill et al. 2000, Men'shchikov et al. 2001 and the summary in Monnier et al. 2003), whilst remarkable images of the outer region show complex arclet structures (de Laverny 2003). Furthermore CO observations show the shells of carbon variables (mostly classed as semi-regular) to be clumpy (e.g. Olofsson et al. 1996, 1998).

It is interesting to note that obscuration events appear to be relatively rare in single oxygen Miras (see Whitelock et al. 2000 and also Bedding et al. 2003). It is not clear whether or not this difference between carbon and oxygen Miras could be due to the type of particle involved. Whitelock (1987, 2003) has drawn attention to the fact that obscuration minima are relatively frequent in symbiotic systems containing oxygen Miras. She suggests that this might be due to the wind from the hot component in the system producing inhomogeneities in the distribution of the dust.

The long term modulation of the light curves of carbon Miras by dust clouds ejected in the line-of sight is similar in principle to the model for the obscuration minima of R Coronae Borealis (RCB) variables, with the star itself left unchanged (a good example of this in the case of the pulsating RCB star RY Sgr is given in Feast (1979) and reproduced in Clayton (1996)). If the C_2 bands seen in emission dur-

ing obscuration phases of some carbon Miras (Lloyd Evans 1997) come from the outer atmosphere of these stars they could be explained as becoming visible when the main body of the star was dimmed by a dust cloud. This is the model for the emission spectrum seen in RCB stars during minima (Feast 1979). Whitelock et al. (1997) note some similarities between the long term variations of R For and RCB stars. Some differences between the details of the Mira obscuration phases and those of typical RCB stars, are, however, to be expected in view of the major differences between the size and temperatures of the stars involved, the order of magnitude difference in the expansion velocities of the circumstellar material, and possible differences in the effective reddening law of the shell.

Understanding the formation of the dust is a formidable problem and it remains to be seen whether the theoretical advances cited above can be combined with an asymmetrical ejection (dust cloud) model. The basic cause of asymmetrical mass ejection may be non-uniformities in the stellar atmosphere. At least in the case of oxygen Miras, interferometry has indicated departures from circular symmetry which might be due areas of different brightness (and temperature) (e.g. Lattanzi et al. 1997), possibly large convection shells. It has also been suggested (Soker & Clayton 1999) that dust formation in both AGB and RCB stars takes place preferably above cool magnetic spots. Alternatively, instabilities in the dust forming region itself may lead to the formation of dust clouds (Woitke et al. 2000).

4 CONCLUSIONS

Superposed on the pulsational brightness variations of II Lup at J there is a long term, large amplitude variation. This is complex and, as in the case of R For (Whitelock et al. 1997) and probably other stars, it is not easily fitted by available models which predict long-term periodic variations for mass-losing carbon Miras. These models are spherically symmetrical. Combining our $JHKL$ data with the high resolution work of Lopez et al. (1993) allows us to conclude that the effective reddening law of the circumstellar material at J and H is similar to that found for R For (Feast et al. 1984). The overall properties of the star itself and the radiation from the circumstellar dust have remained practically constant over the ~ 18 years of observation. The long-term variations at J are attributed to a dust cloud or clouds ejected in the line-of sight. Taken together with other evidence the most likely model for objects of this kind is a quasi-spherical dust shell, formed in material moving away from the star, with small scale irregularities which can produce large variations in the line-of-sight absorption as they form and disperse. The model is then similar to that proposed for RCB variables which are also carbon-rich (though hydrogen deficient). It is hoped that future interferometric work will be able to test the model we propose for II Lup.

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